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Crosby, William Otis

Physical history of the Boston basin.

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TEACHERS' SCHOOL OF SCIENCE

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Boston Society of Natural History.

LOWELL FREE COURSES.

1889–90.

Physical History of the Boston Basin.

BY

W. O. CROSBY.

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TEACHERS' SCHOOL OF SCIENCE.

1889-90.

PHYSICAL HISTORY OF THE BOSTON BASIN.

By W. O. CROSBY.

FIRST LECTURE.

THE OUTER ISLANDS OF BOSTON HARBOR.

Lovell's, Gallop's, George's and Great Brewster Islands are drift covered, consisting mainly of typical drumlins showing marine erosion, but in part of recent deposits of sand and shingle—beaches, spits and bars—due to the constructive action of the sea. Great Brewster is an exceptionally good example of eroded drumlins; and the bars connecting it with the Boston and Bug Lights are among the finest illustrations in this vicinity of the active agency of the sea in the formation of new land.

The remaining islands of this group are almost or quite driftless, and form part of a great synclinal fold of slate, with intrusive beds of diabase. After the quiet deposition on the sea-floor of a great thickness of clayey sediment or mud, which, by hardening, formed slate, the beds were compressed horizontally and bent so as to form a concave arch or syncline. And during the folding of the slate cracks were formed through which melted rock (diabase) rushed up from below and then spread out between the layers of slate, forming more or less regular sheets of diabase parallel with the slate above and below. Calf Island lies on the north side of the syncline and the Brewsters on the south side. Calf Island is crossed by two great intrusive beds, with a bed of slate about thirty feet thick between them. The lower or most northerly of these two beds of diabase must be several hundred feet thick and forms the whole of Little Calf and Green Islands, the Roaring Bulls and the Graves. Near the slate, especially, the diabase possesses a very coarse and perfect flow-structure; and it also exhibits on a large scale the concentric structure characteristic of many massive eruptive rocks.

The best exposures showing the alternating beds of slate and diabase are on the south side of Middle Brewster Island. And since the igneous sheets of the outer islands are not only clearly and typically intrusive, but also admirably exposed for study, they merit the especial attention of all students of our local geology, as affording a valuable standard for comparison in determining whether the eruptive masses in other parts of the Boston Basin are intrusive or contemporaneous.

HULL, OR THE NANTASKET PENINSULA.

This district embraces two strongly contrasted areas: (1) Nantasket Beach and the Village of Hull, consisting of partially eroded drumlins connected by broad and more or less protective beach formations. (2) The Nantasket ledges, an almost driftless area of very complex structure. These ledges teach us that during the slow accumulation, over the fundamental granite of the beds of gravel, and shingle, which, by hardening, formed the conglomerate or puddingstone of Roxbury and other localities about Boston, in ages before the deposition of the slate, there were occasional volcanic eruptions in different parts of the Boston Basin, the liquid lava often flowing down over the beaches and covering the newly formed beds of sand and gravel, to be in its turn covered by still newer sedimentary beds. And this intermittent volcanic action continued so long that we are now able to make out half a dozen or more alternations of beds of lava and beds of conglomerate.

Long afterward, when the slate had been deposited over the Nantasket area, these beds were not folded, as in the outer islands, but slightly tilted toward the south and then broken and displaced by numerous faults, the faulting being attended by the formation of three series of dikes. But, while the dikes and faults, especially, present features of great interest, the value of the Nantasket ledges really culminates in the very clear light which they throw upon the relations of the beds of conglomerate to the ancient lava-flows of this region.

The igneous rocks of Nantasket testify to the existence of great volcanic activity in this region during the formation of the conglomerate. While the outer islands tell us that this period was followed by one of deeper water and great tranquility when the slates were slowly deposited; and then a period of general disturbance and igneous activity supervened, during which the conglomerates and slates were folded up, faulted and cut across by numerous dikes, some of which were intruded between the beds of slate, forming the *intrusive beds*. Hence we may regard Nantasket as the most favorable point in the Boston Basin for the study of contemporaneous beds or true surface flows of lava, as the outer islands are the most favorable point for the study of the intrusive beds or dikes, parallel with the strata, dating from the later period of igneous activity.

The best points to observe the contacts between the beds or flows of old lava (melaphyr) and the beds of conglomerate are: Long Beach Rock; the east side of the railroad, north of Great Hill; the ledges projecting farthest to the northwest, at the mouth of Weir River (the Nantasket steamers pass very near these just before reaching the wharf); and Rocky Neck, on the west side of Weir River, in Hingham. Several contacts of the melaphyr and beds of volcanic tuff are well exposed along the northern base of Atlantic Hill. The interesting relations of the conglomerate to the granite are most clearly exhibited on the south side of Rocky Neck, and along the eastern shore of Weir River, opposite Rocky Neck. Clear examples of faulting exist in Long Beach Rock and the ledges immediately east of the railroad; while the most of the defiles and escarpments of the district mark the positions of faults. The dikes may be studied to the best advantage along the shore between Nantasket Beach and Green Hill, and also along the shore west of the Rockland House. They belong to three systems, according to their directions. A double dike of the first or oldest system is clearly cut by a dike of the second system in the ledge east of Gun Rock; and two dikes of the second system are cut by a small dike of the third or newest system on the north side of Green Hill.

October 12th.

SECOND LECTURE.

HINGHAM.

Although Hingham presents no single feature or type of structure of surpassing importance, such as have been noted in Nantasket and the outer islands, it is a field of very great general interest. It is more comprehensive than the areas already studied, combining the conglomerates and interbedded lavas of Nantasket with the slates of the outer islands; and it is probably true that no other part of the Boston Basin comes so near being an epitome of the whole as Hingham.

Hingham is divided into two distinct and very unequal areas by the line separating the granitic from the sedimentary rocks. This line coincides, in a general way, with the east and south sides of the harbor, runs a little south of the railroad between Hingham and West Hingham, and thence in a direct line to Weymouth Back River, south of Beal's Cove. But north of this boundary, west of the harbor, there is a large peninsula of granite underlying Bradley's, Squirrel and Baker's Hills. South of this boundary, and covering all the main part of the town, the granite is uninterrupted, except by two or three considerable belts and numerous smaller masses of diorite, and still more restricted occurrences of felsite. These rocks are limited to the northern part of the granitic area; and their distribution has been carefully worked out by Mr. Bouvé. The diorite is clearly older than the granite, which cuts through it in numerous irregular dikes, or encloses angular fragments of it. The best point to observe this relation is on the top of Fort Hill, west of West Hingham Station.

While the granite is always newer than the diorite, the felsite is, in the main, at least, newer than the granite. The felsite is less abundant than the diorite, and usually forms irregular dikes, cutting through the granite, as on Lincoln Street, near the church. But the breccia structure of the remarkably beautiful red felsite found in the vicinity of Lincoln Street and Bradley's Hill, indicates that it was formed as a surface flow of acid lava, and not as a dike. The felsites have in general the same composition as either granite or syenite.

Over an old and deeply eroded surface of these granitic rocks were deposited the sedimentary strata of the northern part of Hingham. A bed of conglomerate was first spread over the uneven granite floor; and, as may be seen north of Beal Street and near Hockley Lane, as well as on Rocky Neck, it is largely made up of angular granitic débris. A period of great volcanic activity then ensued; and the floods of lava, instead of being separated, as in the Nantasket area, by intervals of quiet deposition during which the thick alternating beds of conglomerate were formed, either followed each other very rapidly or this area was temporarily a land surface, for the conglomerate partings are almost wholly wanting and the melaphyr, as shown on the map, and in the ledges, forms one solid bed.

Above this massive bed of melaphyr comes the conglomerate series of Hingham, with ts interstratified beds of sandstone and slate; and the variable character of the strata is a plain indication that the physical conditions were far from uniform during this period. The conglomerate occurs mainly in beds from twenty to eighty feet thick alternating with, usually, thinner beds of gray sandstone and red or gray slate, for a total thickness of nearly one thousand feet. In fact, no other part of the Boston Basin affords such clear and abundant evidence of: (1) frequent changes from beach or shallow water deposits (conglomerate and sandstone) to those formed in deep and quiet water (slate), and *vice versa*; and (2) the oscillations of the earth's crust, upon which these changes usually depend. This intermittent conglomerate series appears to pass somewhat gradually and with perfect conformity up into the great slate series, which consists throughout of a fine, dark gray slate, and has an apparent thickness of at least one thousand feet, without any interstratified beds of coarser material. This is sufficient to prove that the oscillations of level attending the formation of the conglomerate series were followed by a profound and prolonged subsidence; for during all the time when the slate was slowly and quietly deposited, Hingham must have formed the floor of a comparatively deep ocean. But this tranquility could not last forever; for the subterranean forces were slowly gathering strength, and the formation of the slate was undoubtedly terminated, as stated in the first lecture, by the advent of an epoch of severe compression of the earth's crust in this region, in consequence of which the sedimentary rocks were elevated to form dry land, folded, faulted and injected by dikes of diabase. During all the long ages since this geological revolution, Hingham has been mainly, if not continuously, a land area; and the slate, together with the underlying conglomerate, has suffered enormous erosion. These rocks have thus been completely removed from large areas of granite which they once covered; and they are preserved to us now only where they were most deeply folded or faulted down between the granitic masses, and thus protected from erosion.

The South Shore is divided into two distinct geological areas by the great fault along the east side of Hingham Harbor. East of this fault, on Rocky Neck and Nantasket, faults are the predominant structural feature; while west of it the strata are strongly folded and the faults are of subordinate importance. The best localities for observing the alternating beds of conglomerate, sandstone and slate, as well as the folds and faults, are: (1) between Melville Garden and the great mass of melaphyr on the west; (2) northwest of Squirrel Hill; (3) between Beal Street and Beal's Cove; and (4) in the ledges along South Street and especially in the vicinity of Hersey Street. The first locality gives us an overturned synclinal fold; the second a vertical closed fold; the third a very normal succession of the entire series of strata from the granite up; and the fourth another inversion of the beds with several important faults.

The dikes are not a prominent feature, although some of them are very large. The shore about Hewitt's Cove is worthy of a visit on account of the extremely coarse conglomerate found there, and the very perfect jointing and cleavage of the slates. The cleavage is also very perfect on Slate Island.

The drift phenomena of Hingham are as typical as those presented by the hard rocks. The great ice-sheet left the unmodified drift or till chiefly in the form of drumlins, such as Otis, Bradley's, Squirrel, Baker's, Great, Turkey, Planter's and Prospect Hills. During the melting of the ice-sheet, Hingham, with the exception of some of the highest points, was covered by a fresh-water lake or lakes, which stood in succession at different levels, and in which were deposited the horizontal beds of sand and gravel forming the broad plains, such as Liberty Plain, Glad Tidings Plain, Lower Plain and the plain about forty feet above the sea, so well developed along western Lincoln and Beal Streets and also about the south side of the harbor, as well as the numerous plateau-like areas and mounds. Some very typical kames or sharp and winding gravel ridges were also formed, as along the side of Weymouth Back River, north of Great Hill, and in the vicinity of Cushing and Accord Ponds. One of the most interesting facts in the glacial geology of Hingham is the change in the course of Weir River, which undoubtedly discharged into Hingham Harbor in preglacial times. But a kame or narrow plateau, about fifty feet high, on the line of East Street, has deflected the river and caused it to flow over the side of the valley into Nantasket Harbor.

October 19th.

THIRD LECTURE.

NORTH WEYMOUTH AND THE BLUE HILLS DISTRICT.

This western half of the southern margin of the Boston Basin is, like Hingham and Cohasset, a broad area of granitic rocks bounded on the north by sedimentary formations. So far as observed, the granitic area does not, as in Hingham, include any considerable masses of diorite; and only insignificant occurrences of felsite have been noted in Weymouth; but in the main range of the Blue Hills this rock has an important development. The granite of Weymouth, as may be well seen near East Weymouth Station, is mainly the typical variety, of medium to coarse texture, except near the slate, where it is usually fine grained and dark colored; while through East Braintree and the eastern part of Quincy the granite is quite generally finely crystalline, especially, but not alone, in the vicinity of the slate; but farther west, about West Quincy, and to some extent all along the northern border of the hills, we find the dark gray, coarsely but uniformly crystalline granite of the quarries, the so-called Quincy *syenite.* The felsite of the Blue Hills is mainly a dark colored, highly crystalline quartz-porphyry, evidently agreeing in composition with the granite. Although it is at some points a more compact and typical felsite, even showing a distinct banding or flow-structure, and evidently newer than the granite; it may usually be regarded as simply an imperfectly crystalline part and the newest and most superficial part of the granite itself. Great Blue Hill is a solid mass of this rock, and it forms with unimportant exceptions all the summits of the main range as far east as Rattlesnake Hill, south of West Quincy.

The sedimentary rock immediately adjoining the granite of this district, at nearly all points, is an old and more or less altered or metamorphic slate. This slate is so uniform throughout as to indicate that it all belongs to the same formation. Fortunately, one of the most typical exposures is the celebrated Trilobite Quarry on the south side of Hayward's Creek, in Braintree, and the large *Paradoxides* and other fossils found here prove these strata to be of Primordial (Lower Cambrian) age. It is thus known that they were formed very far back in geological time, and belong near the base of the recognized geological formations.

The exact contact between the granite and slate is well exposed at many points and clearly establishes one of the most important facts in the geology of the Boston Basin, viz., that the granite is eruptive through and, therefore, newer than the Primordial slate. Two very instructive excursions may be made along the border of the granitic area for the purpose of studying the relations of the granite and slate. The first excursion begins most conveniently at North Weymouth Station. Crossing the margin of the great sand plain to Mill Cove, we find ledges of granite, and immediately north of them, separated only by a large dike, is about 750 feet in breadth of nearly vertical slate. The beds of slate nearest the trap and granite are plainly altered by the heat of these igneous masses, showing a coarse amygdaloidal structure, with segregations of epidote, chlorite, etc In North Weymouth Village, south of the railroad, a considerable body of slate appears to be entirely enclosed in the granite. The two cuts on the railroad, between Weymouth and North Weymouth Stations, are especially interesting. The actual contact of the granite and slate is laid bare for considerable distances, the granite presenting a smooth, solid wall, with the powerfully compressed and broken slate resting against it. Although the compact and even felsitic texture of the granite along this line indicates that it is eruptive through the slate, the present contact is undoubtedly a fault plane; and the thermal waters flowing upward along this fault in the past have decomposed the rocks on either side and formed the numerous quartz veins, which begin at the contact and extend outwards into the slate. The narrow belt of slate extending westward along the Monatoquot River, and to the relative softness of which this part of the valley owes its existence, affords many outcrops of the nearly vertical green and gray slates, but no satisfactory exposure of the contact with the granite. Passing northward to the mouth of Hayward's Creek, the massive gray slate containing the trilobites has been observed in contact with the granite just east of the quarry, and the granite is clearly eruptive through the slate. North of Hayward's Creek the slate extends westward into the granite, and the typically igneous contact is repeatedly exposed.

The second excursion begins at the crossing of Adams Street and the railroad, in Quincy. Going west, the slate is observed on both sides of the street, with the granite farther south and largely concealed by a group of drumlins. On the rocky slope north of the granite quarry, east of Common Street, several belts of distinctly altered or metamorphic slate are seen to be entirely enclosed in the granite, with dikes of granite breaking through them. Essentially the same phenomena are repeated at intervals all along the border of the granite, between the Granite Branch Railroad and Randolph Avenue. Turning south on Randolph Avenue, across the first or northren line of granite hills, we come upon a belt of slate nearly half a mile wide and two miles long, the more rapid erosion of which has produced this broad intervale between the northern range and the southern or main range of the Blue Hills. East of the avenue, the slate is clearly intersected by numerous dikes of granite as well as trap. It is noteworthy that throughout the South Shore district the boundary between the granite and slate is often marked by one or more immense dikes of trap.

While, as we have seen, the slates bordering the granite between North Weymouth and Milton must be regarded as older than that rock; it is equally clear that the conglomerate of this region, as of the Boston Basin generally, is newer than the granite, since it is composed, in large part, of pebbles of granite. After the formation of this old Primordial slate, and the eruption of the diorite, granite and felsite, these rocks were largely worn away; and the detritus thus produced was assorted and stratified to form the conglomerate and interstratified sandstone and slate, which are such a prominent feature of the geology of Hingham. During the deposition of the conglomerate series, there was, as in Nantasket and Hingham, some volcanic activity, giving rise to interbedded flows of melaphyr. The conglomerate series appears to pass gradually upward into the great slate formation; and one of the most difficult problems in the geology of the Boston Basin is the distinction of the slate above the conglomerate from the Primordial slate, where the structure is complex and largely concealed by drift deposits.

The ridge of melaphyr on Hough's Neck marks the crest of a sharp anticline, bordered on either side by conglomerate, passing into slate. The conglomerate and slate, without the melaphyr, are well exposed again on the railroad, and along Black's Creek to the westward. Farther west, these newer sedimentary rocks are seen in the vicinity of Pleasant Street; and there are good sections on Randolph Avenue and Robbins Street; but the conglomerate appears to change to sandstone in this direction.

The Blue Hills undoubtedly owe their relief chiefly to the superior hardness and durability of the granite and felsite, and their rounded outlines are characteristic of the massive granitic rocks. It is very noticeable, however, that the southern slope is almost always the steepest, as in the Great Blue Hill; and their north-south profiles thus show the stoss and lee-crag aspects peculiar to well glaciated elevations.

There are about fifteen typical drumlins in this district; but they scarcely encroach upon the area of the Blue Hills, being confined chiefly to the lower ground on the east and north. They are bordered and separated by the broad level plains of modified drift. Near the sea, the elevation of the plains rarely exceeds twenty feet. Higher plains (forty to sixty feet), with very typical kames, occur in North Weymouth; and in Quincy, west of the railroad. They exhibit many fine kettles, but are otherwise broken only by the drainage channels.

October 26.

FOURTH LECTURE.

THE NEPONSET VALLEY.

The country between the northern line of the Blue Hills, in Quincy and Milton, and the immediate valley of the Neponset is almost a blank, so far as the hard rocks are concerned. With the exception of the old slate quarries in North Quincy and the ledges of conglomerate, melaphyr and slate referred to in the third lecture as occurring on Hough's Neck and along Black's Creek and the northern base of the hills, this area, which is about one mile broad in the vicinity of Randolph Avenue and nearly four miles along the shore and embraces some ten square miles, is covered continuously by drift deposits, including Fairmount or Brush Hill, Milton and Forbes Hills and several minor drumlins and the wide-spreading sand plains. This mantle of drift crosses and fills the Neponset Valley, between Squantum and Milton Lower Mills; and again between Hyde Park Village and the Great Blue Hill. But through the intervening portion of the valley and on Squantum the outcrops are sufficiently frequent to afford a clue to the geological history and structure.

The prevailing sedimentary rock of this district is conglomerate; and the attitude or structure of the conglomerate as a whole is anticlinal. It dips toward the north along the northern border of the belt, passing beneath the deep and narrow syncline of slate in Dorchester and West Roxbury; while along the southern border the dip is southerly and it passes below the much broader syncline of slate believed to underlie the drift deposits of North Quincy and Milton. Toward the west this broad anticline of conglomerate is divided by the irregular ridge of the old, crystalline rocks which projects into the basin from the granitic area of Dedham and Needham, and includes the granite in Bellevue Hill, and the felsites in the northern part of Hyde Park and north of Mattapan. This simply means that the western half of this great fold has been eroded so deeply that the conglomerate and melaphyr have been entirely removed from the top of the arch, exposing a wide area of the ancient floor on which they were accumulated. But the structure of the Neponset Valley is by no means so simple as this outline would indicate; for this great arch is complicated by several sharp synclines and broken in various directions by numerous important faults.

In fact, this is, geologically, one of the most complex and difficult areas in the Boston Basin. At least three beds of melaphyr and one important bed of porphyrite are interstratified with the conglomerate; and during the geological revolution or period of disturbance following the accumulation of these rocks and the overlying slate upon the old floor of felsite and granite, they were forced into a gigantic arch from one to three miles broad. This great fold, however, partially broke down in the making, and its collapse was attended by the formation of the minor folds and the numerous faults already referred to. The subsequent erosion has been so extensive as to remove the entire thickness of slate from the crest of the great anticline, except where it has been carried down most deeply by these minor folds and the faults, occurring now in narrow belts wedged in between the larger masses of conglomerate. The erosion has also been sufficient to cut through the whole series of conglomerate and melaphyr where they were most elevated and thus expose the old foundation of felsite and granite. This, as stated, is the explanation of the long area or tongue of these ancient rocks extending east from Dedham, and also of the smaller areas of felsite between the Neponset and Pine Tree Brook, and along Blue Hill Avenue, in Milton.

While the correlation of the different parts of the Neponset Valley and the determination of the structure of the whole is thus an exceptionally difficult problem, it is also true that almost every section or natural division of the district is replete with interest; and in no other part of the Boston Basin do we find material for so many instructive field-lessons. This valley, as a geological area, is continued in the islands of the harbor; and it may even be regarded as including the outer islands, as far as the Graves. The inner harbor embraces no point of greater geological interest than the western end of Rainsford Island and the adjacent Quarantine Rocks. The slate beds here form a broad synclinal fold. They exhibit a very distinct cleavage across the stratification, and near the middle or axis of the syncline, especially, they are wonderfully contorted in rather a large way, nearly every known type of fold being well illustrated here. The same slate is seen again in the old quarries of North Quincy; but the beds here are nearly vertical, free from contortions and beautifully jointed.

The excellent section of the strata on the outer end of Squantum affords a valuable study on account of: (1) the nearly perfect cleavage across the bedding of the staty conglomerate on the north shore; (2) the extreme coarseness and irregularity of some of the conglomerate; (3) the repeated alternation of thin layers of sandstone and brownish slate; (4) the faults, which are clearly developed on both a large and a small scale; and (5) the rather clear indications of important closed and overturned folds. The salt marshes of Squantum and the lower Neponset are among the most typical and accessible in this vicinity.

The geological interest culminates in the numerous ledges in the immediate vicinity of Milton Lower Mills. The extended natural sections across the strata afforded by both banks of the river, below the falls, and especially by the east bank, are unequalled in this region for the very numerous alternations of conglomerate, sandstone and slate which they exhibit. There are also some good exposures of ripple-marks; and several faults are very clearly indicated. In fact, the impossibility of correlating directly the sections on the east and west banks shows that the river departs from its usual east-west course here to follow a prominent fault line. The slate forming both banks of the river, just west of the mills, is of great interest on account of its highly irregular dips. On the north side it shows large contortions, like those on the Quarantine Rocks, while the railroad cut on the south side runs obliquely through an unsymmetrical anticline. North of the river several faults are clearly shown in the conglomerate and slate; and the large puddingstone quarry on Codman Street should be visited to observe the dikes and the contact with the overlying slate. Farther west, toward and about Mattapan, there are several interesting belts of slate; and the relations of the conglomerate to the melaphyr and porphyrite and to the beautifully banded and brecciated felsites are well exposed, but very intricate.

The best opportunities for study in this direction, however, are to be found in the vicinity of Central and Blue Hill Avenues, in Milton. It is especially plain on Central Avenue that the conglomerate rests directly upon the felsite and is interstratified with three flows of melaphyr and one of porphyrite. The structure is greatly but not hopelessly complicated by the numerous faults. The clear fault-contact of the felsite and conglomerate immediately on the Avenue, with the cleavage of the conglomerate and the pinite in the felsite, and the fine exposures of typical breccia near by, merit particular attention.

The recent or glacial geology of the Neponset Valley is very normal in its development and far less difficult than the hard rocks. The drumlins include two of the largest in the Boston Basin, Milton Hill and Fairmount. The sand plains or plateaus with their attendant kettles and kames are well developed at four different levels, the elevation, as usual, increasing as we recede from the sea. East of the Old Colony R. R., the lowest or 20 foot plain predominates. Between Milton Hill and Fairmount the principal plain is 40 to 50 feet above the sea. North and west of Fairmount there are two plains, the elevation of the lowest and most continuous being 60 to 70 feet, and of the highest or the great plain, 140 to 160 feet. Fairmount and the drumlin to the north of it in Hyde Park Village have obstructed the river to some extent, forming the large swamps south of Readville. The tortuous and rocky channel of Mother Brook shows that the waters of the Charles could not have flowed through here in pre-glacial times; while the falls in the Neponset at Mattapan aud Milton Lower Mills indicate that the river has here been diverted from its preglacial channel by the drift deposits. The long drumlin of Milton Hill was built directly across the old channel, thus diverting Pine Tree Brook as well as the Neponset.

November 2.

FIFTH LECTURE.

THE WEST ROXBURY AND DORCHESTER SYNCLINE.

The conglomerate anticline of the Neponset Valley, which includes several narrow synclines holding some slate beds, and is farther complicated by many important faults, as well as very deeply eroded, is bounded on the north by the well defined belt of slate about half a mile wide stretching east and west across Dorchester and West Roxbury, from Boston Harbor to the Charles River. This is one of the simplest geological areas in the Boston Basin, presenting a striking contrast structurally as well as lithologically to the Neponset anticline. Topographically, also, this slate belt is contrasted with the conglomerate areas on both the north and south. It has been more deeply and smoothly eroded, being essentially a valley between broad ridges of conglomerate. The ledges are few and low-lying, lacking entirely the prominent and broken or craggy aspects of the conglomerate ledges; and the only important reliefs are the drumlins, which greatly obstruct the valley and conceal the slate. The principal exposures of the slate beds are in the vicinity of Dorchester and Blue Hill Avenues, in Mt. Hope Cemetery, and in Roslindale and West Roxbury Villages, especially near the Dedham Branch R. R., which turns aside at Roslindale to follow the level slate valley around Bellevue Hill and the elevated granitic area upon which this drumlin rests. The synclinal structure is not very evident in the slate itself, the beds usually dipping at high angles to the south; but when we observe that the conglomerate on both sides dips toward the slate and appears to pass under it, it becomes plain that the slate must be involved in a deep, closed and somewhat unsymmetrical syncline. This conclusion is in harmony with the fact observed generally throughout the Boston Basin that the slate areas are synclinal and the conglomerate areas anticlinal in structure; and it will not escape notice that this is equivalent to stating that, taking a general view, the conglomerate is older than and underlies the slate. It is not intended, of course, that this generalization should apply to the thin beds of slate which are interstratified with the conglomerate in some places; nor to the older or Primordial slate of the Boston Basin, which is cut by the granite, and upon which both the conglomerate and the newer slate rest unconformably. In summarizing this slate belt, then, we may simply say that from every point of view it appears most interesting and most instructive when compared with the adjoining conglomerate areas.

THE GREAT CONGLOMERATE ANTICLINE.

The broad belt of conglomerate extending from Savin Hill, on Dorchester Bay, across northern Dorchester, Roxbury, West Roxbury, Brookline and Newton to the Charles River is almost uninterrupted by other rocks; and it is at once the largest and most typical area of the conglomerate or Roxbury puddingstone in the Boston Basin. It is bounded on the south by the slate of the Dorchester and West Roxbury syncline, and on the north by the slate which is known to underlie South Boston and the Back Bay and to extend thence as a narrow and somewhat interrupted synclinal belt by the Chestnut Hill Reservoir to Newton Upper Falls.

The conglomerate area varies in breadth from more than three miles midway of its length to one and a half miles along the Old Colony R. R., tapering rapidly toward the eastern end. Topographically it is essentially a broad ridge, the elevation of the numerous bold and picturesque ledges ranging from 100 feet or less near the sea to 200 feet or more in the central and western parts of the area, and averaging 50 to 100 feet above the slate valleys on the north and south.

Geologically, notwithstanding its great breadth, it is one simple, flat-topped and somewhat unsymmetrical anticline. The dip of the strata varies from zero along the broad middle zone or crest of the arch to 60 or 70 degrees on the southern border, and to 20 or 30 degrees on the northern border; the beds passing on both sides beneath the adjoining synclines of slate. This giant fold is not only the largest and simplest anticline in the Boston Basin; but it is nearly midway between the northern and southern walls of the basin; and the lesser folds on the north are to some extent a repetition of those on the south; so that it may be properly regarded as the central and dominant arch in the splendid series which the Boston Basin presents. As with the Neponset anticline, erosion has not only swept away the slate over the entire breadth of the arch, but it has also cut through the great thickness of conglomerate along the more elevated western end of the fold, exposing the underlying melaphyr, and also the felsite, granite and diorite over which the newer rocks were formed.

These old, crystalline, eruptive rocks, which form the southern border of the Boston Basin, are continued around through Dedham and Dover into Needham; but everywhere their relations are essentially the same. The large masses of diorite in Dedham and Dover have been cut through very intricately by the granites; and the felsites, which are well developed in West Dedham and Needham, are clearly newer than the granites, and essentially or chiefly surface flows of acid lava; although, as in the Blue Hills, it is difficult at some points to draw the line between felsite and granite. The eastward extension of these older rocks, dividing the great anticline, properly begins with the large area of felsite in Needham. This is a typical quartz porphyry of very uniform character. A feature of unusual interest, especially as tending to show that the felsite is a surface flow of lava, is the columnar or basaltic structure observed at several points, but having its best development on the railroad, near High Rock.

This felsite is bordered on the north, west and south by melaphyr, which appears to be newer than and to overlie the felsite. The melaphyr is admirably exposed in beds of solid lava, as well as fragmentary lava or tuff, in the vicinity of Charles River Village, on and near the railroad. The most important development of this rock, however, lies to the east of the felsite, in Newton and Brookline; extending about one mile east from the Brookline boundary. This area appears to have been an important centre of volcanic activity, for the melaphyr, including some porphyrite, has a great thickness and is quite varied in character, the appearances indicating a succession of flows. Some of the best exposures of these rocks are on or near Newton, Hammond and Dedham Streets. The island of conglomerate in the melaphyr area, on Greenwood and Dudley Streets, is the only exposure on the anticline of the conglomerate which underlies the melaphyr. Unlike the newer conglomerate, it contains no pebbles of melaphyr. Following this conglomerate and the great thickness of melaphyr above it comes 100 to 200 feet more of conglomerate, and then a final flow of melaphyr some 30 feet thick, before we reach the main body of conglomerate, which stretches away in every direction to the borders of the anticline.

Near the melaphyr, and along the axis of the fold, the conglomerate is often quite coarse, the pebbles becoming smaller as we pass from the lower to the higher beds; but beds of sandstone or slate are rarely interstratified with the conglomerate. The remarkably perfect joint structure of the conglomerate, and the systems of parallel joints, are well exhibited at many points, but nowhere better than in the large quarry on the north-east side of Parker Hill, in Roxbury. Dikes are less common in this anticline than in the more disturbed areas of the Boston Basin; but several of them are well exposed in the Parker Hill Quarry, and one of these, near the east end of the quarry, is a particularly good illustration of the concentric decomposition of the natural joint-blocks of diabase. The largest dike in this district, so far as known, is in the angle between Clyde and Heath Streets, in the western part of Brookline. It is about 100 feet wide and has been traced through the conglomerate for half a mile in a north-south direction. The best exposure is in Clyde Park, where it has been quarried and shows extensive decomposition, yielding rounded masses and fine gravel by the exfoliation of the decomposed material.

November 9.

SIXTH LECTURE.

THE BOSTON, BROOKLINE AND NEWTON SYNCLINE.

North of the great conglomerate anticline the hard rocks are concealed over the large area embracing South Boston, Boston proper (including the South End and Back Bay districts) and the northern part of Brookline. Through a considerable part of this area the rocks have been eroded to a great depth, the thickness of the beds of modified drift (clay and sand) ranging from 100 to nearly 200 feet. This topographic development indicates that the underlying rock is probably slate; and this conclusion is abundantly confirmed by observation. Slate is or has been exposed in natural ledges at several points in South Boston and the city proper; and many artificial excavations, especially the deeper wells, have passed through the superficial deposits into slate. There is a sunken ledge of slate north of South Boston and a very typical variety outcrops on the southern end of Governor's Island. Theartesian well on Providence Street reached the surface of the slate at a depth of 163 feet; and, passing through more than 2000 feet of that rock, ended in the conglomerate at a depth of 2503 feet. The artesian on Causeway Street reached the ledge at a depth of 50 feet; and, passing through a great thickness of slate, appeared also to end in the conglomerate, 1750 feet below the surface. These are plain indications that the beds of conglomerate which, all along the northern border of the great anticline, in Brookline and Roxbury, and especially at the Parker Hill Quarry, are seen dipping towards and, apparently, beneath this large area of slate actually do pass below it and underlie the beds of slate. Although the slate has probably a thickness of, perhaps, a thousand feet, it is unnecessary to suppose that the Providence Street artesian measures the true thickness of this rock at that point, since it probably crosses the beds very obliquely.

The slate of the Boston peninsula appears to be continuous with the broad area of slate known to underlie Cambridge, Charlestown, Somerville, etc. But when we attempt to trace the boundaries of this rock westward from the Back Bay across Brookline and Newton, it is seen to narrow very rapidly, passing like a wedge between the great conglomerate anticline on the south, and the overturned, broken and eroded anticline of conglomerate and melaphyr on the north, in Brighton and Newton. The attitude or structure of the slate is synclinal; and the narrow and interrupted belt of slate extending from Brookline to Newton Upper Falls must be regarded as a mere remnant, left by erosion, of a great, inverted syncline. This part of the syncline has been so deeply eroded that it still holds only the lowest beds of slate; but east of the Chestnut Hill Reservoir it widens and deepens rapidly, as we have seen, and holds the great body of slate underlying Boston.

The slate is well exposed about the lower end of the Reservoir, on the railroad and Beacon Street; and it is known to underlie continuously the southern half of the larger basin. It passes gradually into the conglomerate on both the north and south; and the inversion of the syncline is shown by the beds dipping to the north all the way across the section, although the dip is much steeper on the north side of the fold than on the south side. Between the Reservoir and Newton Centre the conglomerate ledges are so numerous as to prove that the slate is interrupted here. It has either been lifted, by faulting, above the present plane of erosion; or, more probably, it has been concealed below the surface by a powerful thrust-fault. A very clear and typical example of such a fault is well exposed on the east bank of the Reservoir; and it is, perhaps, the most instructive feature in this locality. The next exposure of the slate is in the fine ledge on the north side of Beacon Street, east of Newton Centre. The slate is beautifully laminated and somewhat contorted; and the clear unconformity between it and the conglomerate above it on the north is also best explained by an oblique thrust-fault. South of Beacon Street, and especially along the picturesque escarpment facing the railroad, the conglomerate strata with their joint planes, overhanging bedding planes, ripple-marked sandstone layers and interbedded melaphyr are very instructively exposed. Beyond Newton Centre the slate probably passes north of the ledges of conglomerate and melaphyr about Crystal Lake, under the great sand plain; and reappears between the Newton Circuit R. R. and the river, in several ledges showing ripple-marks and contortions. A brecciated porphyrite is well exposed on Walnut Street, south of Newton Highlands, with clear examples of faulting; and the prominent ledges of conglomerate and melaphyr about Newton Upper Falls afford very instructive exposures of those rocks. The gorge connecting the river between the falls with the pond in Wellesley marks an important fault between conglomerate and melaphyr.

THE BRIGHTON AND NEWTON ANTICLINE.

Between the Boston, Brookline and Newton syncline and the main line of the Boston & Albany R. R., the hard rocks are largely concealed by drift deposits — the great sand plain and the drumlins which rise through it. But the outcrops are sufficient to show that a narrow and nearly continuous belt of melaphyr, a second branch of the large area of this rock in Needham, crosses the Charles River at Newton Lower Falls and extends north-east and east through Newton and Brighton; and that it is bordered on both sides by beds of conglomerate, which are so disposed as to indicate that the melaphyr marks an anticlinal axis. The melaphyr is well exposed at Newton Lower Falls, and again in the vicinity of Chestnut, Valentine and Highland Streets, near West Newton and Newtonville. In this part of Newton the dip of the conglomerate beds, on both sides of the melaphyr, is so great as to indicate that the anticline, in this part of its course, is a narrow, steep-sided and not very unsymmetrical fold.

But farther east the character of the anticline changes, becoming more unsymmetrical; and in Brighton, where the exposures are exceptionally continuous and satisfactory, the anticlinal structure seems to be entirely wanting; for the great arch is here completely overturned and broken down into a faulted monocline. The structure of this very complex area between the Chestnut Hill Reservoir and the Boston & Albany R. R., is strikingly similar to that of Nantasket, although some features suggest comparison with the broken anticline of the Neponset Valley. The southward thrust of this conglomerate arch has crushed and partially concealed the narrow syncline of slate, as already explained. The melaphyr of this area appears to be chiefly, as at Nantasket, in separate flows, interstratified with beds of sandstone and conglomerate; and the relations of the volcanic and sedimentary rocks may be studied to the best advantage in the vicinity of Cambridge, Allston and Warren Streets. No fewer than six beds of melaphyr, ranging in thickness from 25 to at least 200 feet, and one important bed of volcanic tuff, occur here; and not only these, but the numerous faults by which the whole series is broken, as well as the dikes and other geological features are clearly represented on the map and sections prepared by Mr. H. G. Woodward. The actual outcrops are shown on the map; but only the most interesting of these can be mentioned. The high ledge on Washington Street, at the end of Lake Street, shows a thick bed of melaphyr, clearly overlying sandstone. The same relation can be observed at the Pumping Station, on Cambridge Street; and both rocks are here cut by the large dike which is so well known on account of its concentric decomposition. The old quarry on Allston Street shows the sedimentary rock overlying the amygdaloidal melaphyr and clearly cut off by a dike-fault. The ledges of melaphyr and slate lying south-east from the end of Allston Heights are interesting on account of the numerous transverse faults, the branching dike of diabase and the two large dikes of melaphyr. The contact of the latter with the slate is highly irregular. The old quarry on Warren Street affords a good exposure of the bed of tuff, and it was, when worked, the best place in the Boston Basin to observe ripple-marked strata. The sections on Commonwealth Avenue, both north and south of Washington Street, will repay careful examination, especially for the faults, joints, dikes and the large horizontal fold or quarter bend of the strata. The Brighton district is an excellent place to note the dependence of the topographic reliefs upon the harder rocks, the elevations, and especially the ridges, consisting almost wholly of melaphyr and conglomerate.

November 16.

SEVENTH LECTURE.

THE CHARLES RIVER VALLEY.

The Charles River enters the Boston Basin at its extreme western extension, that is, at the point where the sedimentary and volcanic rocks of the basin are now found farthest inland. A narrow and broken synclinal belt of melaphyr and conglomerate extends from northern Medfield, or possibly Medway, between Dover and Sherborn, and through the south part of Natick into Wellesley. For the most of this distance, and especially in Natick, the river follows the southern margin, rather than the axis, of the fold, defining the boundary between the melaphyr on the north bank and the felsite and granite on the south bank. But the Sudbury River aqueduct has found its easiest path along the line of conglomerate ledges extending from the eastern border of Natick under the large drumlin near South Natick Village and thence across Cottage Street to the base of the low drumlin on Rockland Street just north of Everett street. Farther west on this line the ledges are all granite and felsite.

The scattering ledges south of the Boston and Albany Railroad, in Wellesley, indicate that this belt of conglomerate and melaphyr is continuous under the great sand plain from the vicinity of Lake Waban to Riverside. The river, however, instead of pursuing this direct geological course, turns abruptly to the right at the mouth of Dewing Brook and makes its wide and tortuous détour across the strike of the sedimentary formations and over broad areas of the hard crystalline rocks — felsite, granite and diorite, lengthening its channel between the points named from three and one-half to nineteen miles. Through that part of its course where it forms the common boundary of Dover and Needham it also marks the boundary of the Boston Basin, separating the granite on one side from the melaphyr on the other. It is then bordered wholly by the old granitic rocks as far east as Spring Street in West Roxbury. But from this point, instead of following the West Roxbury and Dorchester syncline of slate eastward to the sea, it runs northwest across this deep fold, across the great central anticline of conglomerate, cutting deeply into the underlying felsite, across the Boston, Brookline and Newton syncline, and finally across the melaphyr axis of the Brighton and Newton anticline, at Newton Lower Falls.

Immediately north of Riverside the river reaches the northwest border of the basin, and appears to follow the margin of the granite and diorite closely as far as Waltham. The level sand plain on which Waltham is built overlaps the boundary between the sedimentary and crystalline rocks at some points; but still it may be regarded as defining with substantial accuracy this northwest angle of the Boston Basin, above which Prospect Hill rises as a prominent land-mark, matching Great Blue Hill at the southwest corner of the basin. The broad area between the Boston and Albany Railroad, or the Brighton and Newton anticline, and the continuous wall of diorite and granite forming the northern rim of the Boston Basin from Prospect Hill to Arlington Hights, and extending east from Waltham to Somerville, is an almost unbroken mantle of drift deposits — drumlins, sand plains and beds of clay. But the topography and such outcrops as have been observed, as well as the evidence afforded by artificial excavations and wells, prove that the underlying rocks must be chiefly slate. There are also indications that while the general structure of this area is synclinal, the slate beds are, in the western part at least, involved in a series of anticlines and synclines. Hence this area may be regarded as corresponding in geologic structure as well as in geographic position with the similar drift-covered area between the Neponset River and the Blue Hills. The large ledge of slate north of the railroad, in Newton, shows irregular dikes and fine examples of contortions or minor folds, recalling the Quarantine Rocks and Hangman's Island in the southern area. This ledge marks a synclinal axis; while the outcrop of conglomerate between Mt. Auburn and Belmont Streets in Watertown, with the slate beds dipping away from it on both sides, is very clearly the crest of an anticline which has been eroded just deeply enough to expose the conglomerate below the slate.

In Watertown and Cambridge, and those portions of Belmont and Arlington lying within the Boston Basin, the widespread sand plains and clay beds cover the ledges almost or quite continuously; but in Somerville the drift is accumulated chiefly in drumlins, and over the intervening areas the slate beds and the intersecting dikes are frequently exposed, and have been extensively quarried at various points. The strike of the slate is northwest and southeast, parallel with the Mystic on one side and the Charles on the other; and we are thus able to explain the southeasterly courses of these rivers. The prevailing dip of the slate is southwest, or toward the Charles River, and away from the Mystic, usually at low angles, but becoming steeper toward the Mystic. South of the Charles, in Brighton, the slate dips north and this part of the valley is thus plainly synclinal; but it is probable that the apparently great thickness of the slate in Cambridge and Somerville is due in part to important faults parallel with the strike of the beds, although the homogeneity of the slate makes it difficult to locate the displacements.

The valley of the Charles River presents the broadest and most continuous developments of the sand plains and other forms of modified drift in the Boston Basin. South and west of Riverside, especially in Natick, Wellesley, Needham and Newton, the great plain, 140 to 160 feet above the sea, prevails; while north and east of that point, in northern Newton, Waltham, Watertown, and Cambridge, or over the broad slate valley between the Brighton and Newton anticline and the northern border of the basin, the plains descend by steps from 60 or 70 to 40 and 20 feet above mean tide; and near and below sea level, in Belmont, Arlington, Cambridge, etc., the clay beds have an extensive development. The great magnitude of the deposits of clay in this region, and especially in the lower valleys of the Mystic, Charles and Neponset, is made apparent by borings showing that the true rock bottoms of these valleys are now from 100 to 200 feet below the level of the sea. The kames are exceptionally well developed in the vicinity of Riverside, along the Charles below Stony Brook and at the Waverley Oaks. There are several fine groups of drumlins in Dover, Natick, Watertown and especially in Somerville. Drumlins are not wanting in Needham and Wellesley, but they are largely buried in the great plain. The great bend of the Charles probably originated in geological conditions which were long ago effaced by erosion, for it is not the drift deposits alone, but solid ledges, which now prevent it from following the direct course between South Natick and Riverside. The portion of the great bend east of the line ditch, in Dedham, is due, however, to the fact that the drift completely filled the old channel of the river at Newton Upper Falls, raising the level of the stream at least 25 feet, thus forcing it not only to pour over the conglomerate ledges, in which it is now excavating a picturesque gorge, but also to cross the low divide between the river and its tributary, Wigwam Brook, in Dedham, and the divide between the river and Mother Brook, a tributary of the Neponset, thus making Boston an island. Newton Lower Falls require a similar explanation; the ancient, buried channel appearing to be in each case to the west of the modern channel. Dewing Brook, which is parallel with the Charles through the greater part of its course, but flows in the opposite direction, appears to be a good example of a valley whose drainage has been reversed by drift deposits. Beyond Waltham the Charles ceases to follow the boundary of the basin, and wanders aimlessly seaward through its broad drift valley.

November 23.

EIGHTH LECTURE.

THE VALLEY OF THE MYSTIC.

The Mystic River crosses the northern border of the Boston Basin near the lower end of Mystic Pond. This chain of ponds, like Spy and Fresh Ponds, which are tributary to the Mystic through Alewife Brook, appears to owe its existence solely to the contours of the modified drift — the beds of sand and clay — by which it is bordered. As soon as it is fairly across the line, the river turns to the eastward as far as Medford Village to pass around the ledges and drumlins of Somerville. Its course is then southeasterly, following the strike of the Somerville slate and, probably, an ancient fault-line, to the harbor. There seems to be no reason to doubt that this is very nearly the preglacial course of the Mystic; but it is now at a higher level, its ancient channel, as in the case of the Charles and Neponset, being deeply buried by the deposits of clay and sand. The true mouth of the river may thus be located as far out as Governor's Island, near which the Mystic was probably joined in preglacial times by the Charles, the latter stream crossing what are now the Back Bay and South End districts of Boston.

The general relations of the Somerville slates were noted in the seventh lecture. The dip of the slate beds appears to relate them to the valley of the Charles; but topographically they belong more distinctly to the Mystic Valley. The slate is usually distinctly stratified and beautifully jointed; but the interest of the quarries, in nearly every instance, centers in the dikes of diabase, and Somerville may be regarded as, perhaps, the most favorable district in the Boston Basin for the study of this class of phenomena. The largest dike in Somerville, or in the Boston Basin, so far as known, is the great dike which begins in the granite south of Spot Pond and has been traced continuously southward, with a breadth of from 200 to fully 500 feet, through granite and felsite, to Medford Village, where it enters the sedimentary rocks of the basin and appears to pass under the Mystic into Somerville. It is well exposed in the vicinity of the Powder House, on Elm street, and in the large quarry on Granite street. Throughout its entire length, in Medford as well as in Somerville, it is remarkable for the concentric decomposition and disintegration of the rather coarsely crystalline diabase. Two other large dikes can be traced east from the large Alms House quarry and from the south side of College Hill nearly two miles to the quarries north of Winter Hill. While in almost every ledge and quarry there are one or more smaller dikes presenting interesting features for study, such as branches, enclosed fragments, faults, slickensides and other contact phenomena, veinlets of calcite, quartz, prehnite, etc. At some points the main dikes or branch dikes are parallel with the beds of slate, forming fine examples of intrusive beds; and, in general, the irregularities in the strike and dip of the slate can be traced to the disturbing action of the dikes.

The ten hills in Somerville are all drumlins; and to the same group may be added the low drumlin in North Cambridge, Bunker and Breed's Hills and Beacon Hill and its dependent drumlins, Copp's and Fort Hills. The slate ledges rarely rise more than 50 or 60 feet above the sea; the clay beds underlie most of the low ground; and the sand plains have but a scanty development. North of the winding channel of the Mystic, especially, there is a broad expanse of typical salt-marsh underlaid by clay beds; while farther north, but mainly west of the Malden River, is a moderate development of the lower sand plain. The valley of the Mystic, including its tributary, Malden River, is bounded on the east by the magnificent group of drumlins extending from Malden through Everett, Chelsea, Revere and Winthrop to Deer Island, and embracing, with the hills of East Boston, not less than 20 typical and prominent drumlins. They rise mainly from the level of the salt-marshes, and those in Winthrop and on Deer Island are good illustrations of marine erosion. Recent excavations in Somerville, East Boston, Chelsea, etc., also afford instructive sections of drumlins showing distinctly the oxidized and unoxidized portions of the till. Beyond the drumlins of Revere and Winthrop the salt-marshes stretch eastward across the Saugus River to Lynn, relieved only by the low, isolated drumlin of Oak Island, and bordered seaward by Revere Beach, a great natural rampart of sand and gravel.

North and east of the Mystic the sedimentary rocks of the basin are rarely exposed. The most important outcrops are the ledges of conglomerate and quartzite in West Medford. These extend from near West Medford Station eastward along High, Woburn and Purchase Streets to the great dike; and they are especially interesting as being the only known instance of the emergence of the conglomerate from beneath the slates along the northern border of the basin. The conglomerate rests directly upon felsite and fine granite; and, dipping south or away from these older rocks about 20 degrees, it is overlaid conformably by the fine quartzite. The beds are evidently broken by several transverse faults; and the large mass of felsite south of the sedimentary rocks must owe its position to a strike fault on the line of High Street and having the downthrow on the north. Several large dikes break through the granite north of the conglomerate. The slate, with several dikes, outcrops prominently in Malden, west of Rich's Meadows and north of the great series of drumlins; and it is exposed again, and for the last time in this direction, on the Newburyport Turnpike, at Maplewood Station. The numerous bowlders of sandstone and conglomerate in Chelsea and Revere indicate that these rocks have an important development in this part of the Boston Basin, but they are entirely concealed by the drift; and the only known outcrop in all the large area south of Malden and Saugus is the great mass of trap with enclosed fragments of granite at the west end of Powder Horn Hill.

NAHANT.

The northern rim of the Boston Basin, which we have traced as a continuous range of high land from Waltham to Malden and Saugus, reaches the shore in Lynn and Swampscott; and Nahant is the last point along this line where the newer sedimentary rocks, or those belonging within the basin, are exposed above the water. The geology of Nahant has been very carefully and thoroughly studied by Mr. A. C. Lane, and the following statements have been, in large part, condensed from the abstract of his monograph in the Proceedings of the Boston Society of Natural History.

Nahant consisted originally of three rocky islets—Nahant, Bailey's Hill and Little Nahant, which have been joined to each other and to the main land by very typical barrier beaches. The prevailing rock is a coarsely crystalline diabase. On the north shore, near Maolis Garden, the flow structure of this diabase is very pronounced over a small area; but elsewhere it is quite massive. It is rich in magnetite at some points; and small veins and irregular segregations of epidote are very common in it, especially on the south shore, east of the steamboat wharf. The most interesting and attractive geological feature of Nahant is the slate and interstratified limestone forming the picturesque cliffs in the vicinity of East Point. Some fossils have been recently found in the limestone layers by Mr. Foerste and others and it is probable that the study of these will give us a more definite idea of the age of these rocks. The limestone also affords the only opportunity in the Boston Basin to observe the erosion of calcareous rocks by simple solution. All these strata dip northwest or toward the land; and they probably pass beneath the great mass of diabase. The slate reappears on the north side of Little Nahant; and it is probable that this rock forms a synclinal fold, as in the outer islands, which holds the diabase as a great intrusive bed, the overlying slate having been removed by erosion. About 500 dikes have been observed by Mr Lane, breaking through the diabase and slate; and through the combined influence of these and the great intrusive bed the slate has been indurated to lydite and otherwise altered, containing segregations of massive garnet and other minerals.

December 7.

NINTH LECTURE.

THE NORTHERN BORDER OF THE BOSTON BASIN.

The topographic development of its northern rim is one of the finest features of the Boston Basin. Although it scarcely exhibits in any part the distinctly mountainous character of the Blue Hills on the southern border, it is a much longer, more continuous and more sharply defined range of high land, presenting an almost unbroken wall of crystalline rocks for thirty-five miles, from Marblehead to Natick. Marblehead Neck and the Swampscott shore may be conveniently regarded as the northeast corner of the Boston Basin, corresponding to the Cohasset shore at the southeast corner. This shore is the eroded edge of a rocky plateau from 50 to 100 feet in height, embracing Marblehead, Swampscott and Salem. In Lynn the border of the plateau begins to recede from the shore, and the crystalline rocks rise to greater heights; but the plateau character is less distinct on account of the numerous ponds and streams. From Lynn westward as far as Waltham the elevation of the plateau ranges from 100 feet in the valleys to over 300 feet; and its southern edge, the true border of the basin, is at most points a remarkably well defined slope, if not an actual escarpment, overlooking the low land of the basin. The plateau is deeply divided by the Saugus, Malden and Mystic Rivers; but its edge is simply notched by the smaller streams, such as Arlington, Clematis and Beaver Brooks. The contour lines of the new State map bring out this wall of the older rocks with great distinctness; and its course is marked in part also by the Mystic River and the railroads. While there has undoubtedly been extensive faulting along this line in the remote past, we must consider that, as in the case of the Blue Hills, forming the southern border of the basin, the crystalline rocks owe their present relief mainly, if not wholly, to the superior resistance which they offer to erosion. At Waltham the border of the basin, as previously noticed, bends, with the Charles River, abruptly to the south as far as the Boston and Albany Railroad, which it follows southwesterly across Wellesley. South of the railroad, in Natick, it is less clearly defined as a topographic feature; but its course is marked approximately by the Sudbury River Aqueduct.

The oldest rocks in the large crystalline area, of which we have traced the southern margin, are the quartzites and interstratified slates, which occur mainly in small, isolated patches, scattered irregularly through broad expanses of the massive eruptive rocks — diorite, granite and felsite. These sedimentary strata, including the bed of limestone in Stoneham, are believed to be of Primordial age and equivalent to the Paradoxides slate of Braintree and the Blue Hills. It is at least certain that they are similar in their relations to the eruptive rocks, having been broken through in succession and very extensively by the diorite, the granite, and the felsite, as well as by the numerous dikes of diabase.

At no point along the entire northern border of the Boston Basin are the relations of these older rocks more clearly and instructively exposed than at the eastern end, in Marblehead and Swampscott, and especially on Marblehead Neck. The southwestern end of the Neck is granite, breaking in the most irregular manner through the old slates, which have been metamorphosed to a fine grained schist. The exposures on the shore are exceptionally good, the granite completely enclosing large, jagged fragments of the schist. Northeast of the granite and schist the rock is felsite of many distinct varieties — banded, brecciated, porphyritic, quartz-porphyry, etc.; and dikes of felsite may be observed in the granite near the contact of the two rocks. The porphyritic trachyte overlying the banded felsite on the north shore is a distinctly newer lava. The dikes are interesting, especially in their branching and cross-jointing; and form narrow fissures and chasms by marine erosion, as at the Spouting Horn. The high shingle beach on the ocean side and the sea-worn cliff behind it, and the small beach south of this, affording the garnet and magnetite sand, are also interesting features. On the main land and all along the Marblehead shore diorite is the prevailing rock; but it has been completely shattered at many points by innumerable small and highly irregular dikes of granite, the granite dikes being often so crowded with fragments of diorite as to resemble a breccia. Small masses of schist may also be occasionally observed enclosed in the diorite. On the shore near Clifton Station is an exceedingly fine example of a faulted dike. While on the north shore, and on Salem Neck and the Beverly shore, the diorite has a foliated structure and is injected by a coarse syenite instead of granite, the thin dikes of syenite following the foliation of the diorite and producing a very perfect pseudo-stratification.

Felsite is the prevailing rock in Lynn, Saugus, Malden and Melrose. It exhibits a wide range of color and structure, and is admirably exposed for study at many points. Mr. J. S. Diller has shown that the felsite not only forms dikes in the granite, and is therefore a newer rock, but also that the different varieties of felsite have been erupted at at least two distinct periods. Perhaps the most attractive and interesting variety is the red, compact felsite found near Saugus Centre and commonly known as the "Saugus Jasper." Break-heart Hill affords exposures of the granite where it is eruptive through the sedimentary rocks, rivalling if not excelling those on the southwest shore of Marblehead Neck. The quartzite and interstratified slate form a distinct belt extending from the vicinity of Break-heart Hill through Melrose to and across Spot Pond into Medford, covering several square miles and including the bed of limestone, the so-called Stoneham marble, north of Bear Hill. The best exposures of the quartzite and slate in the Middlesex Fells are in the vicinity of Melrose Station, northeast of Spot Pond and about the southern half of Turkey Swamp. Throughout the Fells district these ancient strata have been broken again and again by successive eruptions of diorite, granite and felsite, as well as by great dikes of diabase. North and west of Spot Pond the diorite covers a large area and is mainly fine grained or compact, resembling the old lava or melaphyr of the Boston Basin; and, like the melaphyr, probably occurring in part as surface flows. The granite has been erupted abundantly through both the stratified rocks and the diorite, the coarsest and most typical development of this rock being about the southern end of Spot Pond. The felsites occur chiefly in the southeastern part of the Fells, but in the northern part of the district they are most frequently seen cutting through the older eruptives and the stratified series. Among the dikes, the great dike running north from the Mystic towards Spot Pond is pre-eminent; but the two dikes in the eastern part of Winchester which are crowded with large, broken crystals of feldspar must be reckoned among the most interesting in this region. They seem to indicate that the extremely coarse porphyritic granite found farther north, in Middlesex County, is older than and underlies the crystalline rocks bordering the Boston Basin.

Between the Middlesex Fells and Waltham diorite is the all-prevailing rock, felsite being almost entirely wanting and granite occurring mainly as small and highly irregular dikes in the diorite. The diorite is usually massive, but the pseudo-stratification, resulting from a variety of causes — flow structure, compression, and injection by granite parallel with the foliation, — is very perfectly developed at many points, especially near the isolated areas of quartzite and slate. The finest exposure of these stratified rocks is in Shaker Glen, in Woburn. In Weston the coarse, pink granite prevails, the stratified series has not been observed, and the diorite is massive; while in Natick, northeast of the station and also south of the railroad, quartzite is very abundant and both the intersecting diorite and granite exhibit a distinct flow-structure, resembling gneisses. One of the best exposures of massive diorite with irregular dikes of granite is at the quarry on the Fitchburg railroad, between Roberts' and Stony Brook Stations.

The bowlder clay or till was very largely scraped by the ice sheet from this elevated crystalline area into the Boston Basin; and a considerable part of the till that remains is accumulated upon the northern face of the rocky hills, indicating the beginnings of drumlins, but few fully formed and typical drumlins have been observed. Sand plains are well developed in the valleys and occasionally at greater heights up to more than 200 feet. Spot Pond is a clear example of reversed drainage; and the large pot-holes on the Fitchburg railroad between Stony Brook and Roberts' Stations are undoubtedly the finest products of the glacial mills which have yet been observed in this region.

December 14.

TENTH LECTURE.

GEOLOGICAL HISTORY OF THE BOSTON BASIN.

Having in the preceding lessons gone systematically over the Boston Basin and made a somewhat detailed study of the phenomena relating to the composition and structure of the hard rocks, as well as to the drift deposits and other superficial features, we are now prepared to correlate the facts which have been observed and deduce from them, so far as may now be possible, a connected and logical statement of the leading events in the history of this region.

The oldest rocks which we have found are the Primordial slates and quartzites; and the age of these is certainly and definitely known only at the Paradoxides quarry, in Braintree. We appear to be justified, however, in regarding them, provisionally at least, as all of about the same age, partly on account of a general lithologic resemblance, but mainly because their relations to the different classes of eruptive rocks are everywhere the same. In Weymouth and Braintree, where we first met these rocks, they are either typical clay slates or slightly calcareous; but along the northern base of the Blue Hills occasional layers are distinctly siliceous. They probably underlie a large part of the Boston Basin, being covered by the conglomerate and the newer slate; and north of the basin, as shown in the ninth lecture, they occur in isolated areas among the eruptive rocks. In some of these areas, especially in the Middlesex Fells and Melrose, and in Woburn, clay slate similar to that in Quincy and Braintree is repeatedly interstratified with quartzite; while toward the southwest, in Natick, and also in Reading and Lynnfield, there are extensive developments of quartzite with little or no slate. It is very clear that the quartzite north and west of the Boston Basin is the source of the quartzite pebbles which play such a prominent part in the composition of the conglomerate, especially in the central and northwestern sections of the basin. In general, the quartzite is more and the slate less abundant northwestward, indicating that the ancient shore-line along which these strata were deposited lay in that direction; and originally the Primordial strata were probably spread continuously over all the region to the southeast of that line.

The deposition of the Primordial strata was followed by a period of disturbance of this part of the earth's crust during which they were strongly compressed, being thrown into sharp folds having, in general, a northeast and southwest direction. This appears, also, to have been a period of intense volcanic activity. The quartzite and slate were shattered and isolated by great volumes of basic lava, which we now call diorite; and, as indicated by the compact and scoriaceous diorite of the Middlesex Fells and other localities, immense floods of lava were also poured out on the surface, concealing the sedimentary rocks. In breaking through the quartzite and slate, the diorite has often followed the planes of stratification in those rocks, and thus appears in many cases to be regularly interstratified with them; and this bedded appearance of the diorite is greatly increased by the very perfect flow-structure which was developed in large masses of it, as well as by the distinctly schistose or foliated structure sometimes resulting from the subsequent action of both mechanical and chemical forces. We are thus able to explain the fact that the diorite has been frequently mistaken for a stratified or sedimentary rock.

The eruption of the diorite was probably followed by a prolonged period of quiet erosion, which was finally terminated by the advent of a second period of intense and long continued igneous action, during which only acid rocks — the granites and felsites — were formed. All over this region the granite has broken through the Primordial strata and the diorite in the most irregular and intimate manner, sometimes developing a flow-structure similar to that in the diorite, causing the granite to be mistaken for gneiss, and very often following the flow-structure or foliation of the diorite in thin layers or veins, thus producing an imperfect blending of the two rocks and heightening the stratified appearance of each. Over large areas the diorite and granite are so completely mixed in these various ways that it is impossible to represent them separately on the map. The granite embraces many different varieties and some of these are clearly older than others; although all, so far as known, are newer than the diorite. Syenite is well developed in the vicinity of Salem Harbor and to some extent in other localities. It is newer than most if not all of the granite, forming dikes in the latter; but it is very similar to the granite in its relations to the diorite.

The felsite is less widely distributed than the granite, occurring mainly in the immediate vicinity of the Boston Basin. It not only occurs as dikes in the Primordial slate and quartzite and the diorite, but also in the granite. It is unnecessary, however, to suppose that it is widely separated from the granite in time; but it seems best to regard it as in general the most superficial and newest part of the granitic eruptions. That the felsite was formed chiefly as surface flows of acid lava, resembling when new obsidian among recent lavas, is clearly indicated by the banding or flow-structure, the brecciation, and other structural features of the numerous varieties. The different varieties of felsite, like the granites, afford evidence of having been erupted at several distinct but probably not widely separated periods. The granite and felsite are, next to the quartzite, the principal constituents of the conglomerate, their greater durability placing them far ahead of the diorite in this respect. Probably every known variety of both the granite and felsite is represented in the pebbles of the conglomerate; and it is certain, therefore, that the eruption of these acid rocks was followed by a long period during which this region was dry land and suffering erosion, before the deposition of the conglomerate began. General considerations with regard to the climate of that early epoch in the history of the Boston Basin, as well as the absence of pebbles of diorite from the conglomerate, indicate, as Mr. Bouvé has so clearly pointed out, that the wearing away of the hard rocks was due very largely then, as it is now, to chemical action. The diorite and other basic rocks, as is now so well illustrated by some of the dikes about Boston, yield far more readily than the highly acid rocks — quartzite, granite and felsite — to the chemical agency of air and water, and are, therefore, more generally and completely reduced to the condition of an impalpable clay or soil.

An important and long continued downward movement or subsidence of this part of the earth's crust finally began; and as the surface slowly passed below the level of the sea a thick bed of conglomerate was spread over this region, the products of the previous chemical decay of the rocks being rapidly worked over by the waves and the fine silt or clay carried out into the deep water of the ocean, while the coarser materials were strewn along the advancing beach. As has so frequently happened in geological history, this movement of subsidence and the rapid deposition of sediments was accompanied by volcanic activity. The eruptions of this period consist chiefly of surface flows; and they are of a distinctly basic character, melaphyr being the prevailing type, although porphyrite and possibly still more acid lavas are also observed. These were probably mainly crater eruptions, occurring in and near the sea; but we have not as yet been able to definitely locate any of the vents. It is certain, however, that floods of liquid lava were repeatedly poured out over the sea-floor where beds of gravel and sand were forming; and we thus find, as at Nantasket, Brighton, etc., beds of conglomerate and sandstone alternating with beds or flows of melaphyr and porphyrite; but in some cases, as in Hingham, Needham, etc., the successive flows of lava followed each other so rapidly as to form very thick sheets of volcanic rock without any intercalated sediments. Occasionally, also, the eruptions were explosive and beds of volcanic tuff were formed, as at Nantasket, and in Brighton, Newton, Needham, etc. The igneous action was somewhat localized, continuing in some parts of the basin through the entire period of the formation of the conglomerate, while in other parts the lava is wanting or occurs only in the lower part of the conglomerate series.

Alternations of the conglomerate with beds of both sandstone and slate are also of common occurrence, indicating oscillations of level during this period. But the downward movement prevailed, until finally the water became too deep and quiet and too remote from the shore, in this vicinity, to permit the formation of conglomerate and sandstone; but these coarse sediments were gradually replaced by slate during the dying out of the volcanic activity. These tranquil, deep-sea conditions must have continued for a very long time; for the argillaceous sediments accumulate very slowly and yet the slate series has a thickness of from 500 feet to fully 1000 feet or more. The slates are probably somewhat thicker than the conglomerates and were doubtless several if not many times longer in forming. Of the life existing in the sea at this time we, unfortunately, know but little, as the slate is very generally destitute of fossils; and the full chronologic significance of the few organic remains that have been obtained from the layers of limestone in the slate at Nahant is still undetermined.

The deposition of the slate did not end in the same quiet way in which it began, by the gradual elevation of the sea-floor to form dry land. That would have involved a repetition of the shore conditions and deposits; and the conglomerate series below the slates is certainly not repeated above them. But during that long period of quiet deposition of the slate the subterranean forces were slowly gathering strength for renewed activity; and when the weakened crust below the still unconsolidated sediments could no longer resist the growing horizontal thrust or pressure, it yielded; and thus inaugurated an important geological revolution. The slate and conglomerate were powerfully compressed in a north and south direction and thrown into a series of gigantic folds, having a general east-west trend. Although they have suffered enormous erosion, these folds, when not drift-covered, are still distinctly traceable, the anticlines being marked usually by belts of conglomerate and the synclines by belts of slate. The great conglomerate anticline running through the middle of the basin is the central arch in a somewhat symmetrical series of folds. The Dorchester and West Roxbury syncline on the south matches the Boston, Brookline and Newton syncline on the north; and the complex and broken anticline of the Neponset Valley matches the similar Brighton and Newton anticline; while the folds believed to exist in the drift-covered area of slate between the Neponset anticline and the Blue Hills correspond to those in the similar area of slate between the Brighton and Newton anticline and the highlands north of the basin. The strata were extensively broken and faulted, as well as folded; and in some parts of the basin the displacements are a more important structural feature than the plications. The sharply defined northern and southern margins of the basin, as previously stated, are best explained as due to profound faults along these lines. The downthrow in each case was on the side toward the center of the basin, and these two great displacements must be regarded as of primary importance in the geological structure of this region; for, virtually, they present on the upthrow side two solid walls of crystalline rocks between which the great central area of sedimentary and volcanic rocks has first settled down and then suffered compression, as in a vise, by the approach of these north and south walls, producing the great folds already noticed and most of the minor faults of this region. This was also an epoch of great igneous activity, many of the fault and joint fissures being injected by highly basic liquid rock (diabase), forming the great net-work of dikes traversing not only the sedimentary, but also the crystalline rocks. In the slate, especially, the trap has often followed the bedding planes, producing intrusive sheets, sometimes of great magnitude, as at Nahant and the outer islands. If any surface flows or volcanic cones attended the formation of the dikes, they have been completely effaced by subsequent erosion, leaving no sign of their former existence. Perhaps the most important result of this geological revolution was the elevation of this region; and so far as we have any evidence it indicates that the Boston Basin has been a land area, an area of erosion, during all subsequent geological time. The sedimentary rocks have thus been greatly reduced in both volume and area. That they formerly extended far beyond the present sharply defined limits of the basin there can be no doubt, but being there upon the upthrow side of the great marginal faults, they have been completely swept away by erosion.

Quiet erosion, accomplished chiefly by chemical agencies, and finally reducing this region nearly if not quite to a base-level plain, is then, so far as we know, the whole story of the Boston Basin during the vast interval of time separating this period of great disturbance from the marked elevation of the continent which gradually ushered in the glacial epoch. Mechanical erosion was then in the ascendant; but it does not appear probable that the ice-sheet modified the topography so much by the erosion of the hard rocks as by the accumulations of drift which it left upon the surface in the forms of drumlins, sand plains, clay beds and kames. The high land north of the basin was, on account of its elevation, an area, mainly, of glacial erosion; while the detritus scraped from it into the basin made this mainly an area of deposition, as the drumlins testify. During the period of maximum glaciation the ice-sheet extended far to the south and east of Boston, to Cape Cod and Nantucket and possibly much farther. A subsidence of the land finally brought back a milder climate and the margin of the ice-sheet retreated northward. It did not halt long enough in this vicinity to form any distinct terminal moraines; and the ground moraine or till was left chiefly in the form of drumlins. Partly by subglacial streams, but mainly by the great torrents and the temporary lakes resulting from the final melting of the ice, the drift was very largely modified, that is washed, assorted and stratified in the sand plains, gravel ridges or kames and clay beds, which now so generally occupy or fill the old valleys and form deltas where the valleys emerge from the high land bordering the basin. In the distribution of the drift, and especially of the modified drift, we have an adequate explanation of: (1) the ponds, lakes and swamps of this region, as well as the dry kettles or depressions of the sand plains; and (2) the diverted and circuitous drainage and the resulting waterfalls. The elevation of the land during the advent of the ice age enabled the streams to deepen their channels to such an extent that although subsequent subsidence has not, apparently, reduced the land to its preglacial level, the rocky beds of the larger streams are, near their mouths, from 100 to 200 feet below the level of the sea. The fiord character of the shores in high latitudes is usually to be explained in this way. Since the close of the glacial epoch the streams of the Boston Basin, with their greatly reduced slope and volume, have made but little progress in clearing out their drift-encumbered valleys; but along the shore the sea has worked with its usual energy, cutting away the drift formations within its reach and forming extensive beach, bar and marsh deposits. The superficial oxidation of the drift deposits, the chemical decay so marked in some of the dikes, and the organic deposits — peat and tripolite, as well as the bog iron-ore, now forming in many swamps and marshes are other phenomena which must be referred to the present or post-glacial epoch in the history of the Boston Basin.

December 21.

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